

# A Paleolimnological Record from Lake George, New York

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*In this study a 30 centimeter (cm) sediment core taken from the north basin of Lake George was analyzed for changes in diatom community structure. The chronology of these sediments was established using radioisotopic dating methods. A unique and interesting sedimentary profile was observed while retrieving cores throughout the north basin of the lake. The nature of this sedimentary profile, along with supporting evidence from the diatom community, strongly suggests that a low stand occurred in the lake sometime between 200 and 350 before present (BP). The low stand likely predated heavy settlement of the watershed and would have resulted in a several meter drop in*

*lake level. It is possible the lake was rebounding from this low stand as the watershed was being settled. Evidence of the recent onset of cultural eutrophication was also observed in the diatom community structure, and is probably related to development within the watershed. These findings highlight the importance of monitoring and predicting hydrological conditions in the Lake George watershed as human-driven climate change complicates the natural range of rainfall and drought variability in the region. They also provide a context for understanding the current state of the lake and understanding the degree of anthropogenic impacts on the watershed.*

## Introduction

Knowing the history of an ecosystem is an important key to understanding its modern condition and vulnerability to future changes, and paleolimnology can often provide historical perspectives necessary for understanding and protecting aquatic ecosystems. In particular, the siliceous remains of diatoms preserved in lake sediments permit the reconstruction of physical, chemical, and biotic conditions in the past (Anderson, 1989; Cumming, Davey, & Smol, 1994; Dixit et al., 1999; Ruhland, Smol, & Pienitz, 2003).

Lake George is located in the southeastern portion of the Adirondack Park in upstate New York. The lake is known for its clear waters, is a major tourist attraction, and serves as the drinking water source for nearby towns/villages. Research has been conducted on the lake for several decades, most of which has focused on modern limnological

monitoring (e.g. Boylen, Sheldon, & Whittaker, 1981; George, 1981; Long et al., 1981). The few studies that have been done on the sediments of the lake focused on large time scales and were done several decades ago (Bloomfield & Park, 1981; Hutchinson et al., 1981). To our knowledge there have been no studies done on Lake George sediments using modern paleolimnological techniques.

In this study, which represented a senior capstone project conducted by the first author, the sediments of Lake George were examined for signs of recent and ancient ecological changes. The results of this study shed new light on two central questions: (1) Has the northern end of Lake George experienced a cultural eutrophication trend in recent times? and (2) Have climatic changes of the recent past affected the levels of the lake significantly?

## Site Description

Lake George was first "discovered" by father Isaac Joques in the mid-17th century. During the mid-18th century, British troops began construction of Fort William Henry on the southern end of the lake (Bellico, 1992). In 1798, Isaac Kellogg built the first dam on the outlet. The Old Lake House hotel was opened in 1800 along the southern shore of

the lake, marking the start of the local tourism industry. During the late 1800s the Fort William Henry Hotel and the Sagamore Hotel were built along the shores of the southern basin, furthering the development of the tourism industry (O'Brien, 1978). In 1885, the Lake George Association was formed in response to declining fish and game populations, and during the 1890s the Lake George Mirror reported local concerns about fluctuating water levels. Reports from the early 1900s described increased erosion around the lake shore, and by the 1930s shore owners were appealing to the New York State government for regulation of the lake level. Rensselaer Polytechnic Institute first began to study Lake George during the late 1960s. The first watershed management plan (Plan for the Future of Lake George) was published by the New York State Department of Environmental Conservation in 1987. Eurasian Milfoil was first discovered in the lake during the 1970s, and zebra mussels were first documented during the 1990s (Chilson, George, Tucker, & Wheeler, 2003).

Geologically, Lake George is a fault-bounded graben lake that was formed at the end of the Wisconsin glacialiation, when glacial deposits blocked the southern end of the drainage basin (Hutchinson et al., 1981; Shuster, LaFleur, &

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Boylen, 1994). The lake's watershed falls entirely within the boundaries of the Adirondack Park. A single outlet exits the northern end at Ticonderoga and serves as a major tributary to Lake Champlain. The lake is 32 miles long with a mean width of 1.3 miles and a surface area of 43 square miles. The watershed covers 238 square miles and is characterized by rugged mountainous terrain that descends steeply to the lake's shorelines. Mixed hardwood forests cover most of the watershed, and shoreline development is concentrated mainly on the southern and western ends of the lake (Shuster, LaFleur, & Boylen, 1994). Lake George is a circumneutral (pH ~ 7.2) oligotrophic lake (TP ~ 4.5 µg/l), known for its clear waters (secchi depth ~ 9 m; Long et al., 1981). Various species of trout and bass are found in the lake, along with yellow perch, northern pike, brown bullhead, and white suckers (George, 1981). The bedrock geology of the region is dominated by Protozoic meta-sedimentary and meta-igneous rocks. Outcrops of Paleozoic sedimentary rocks, mainly carbonate-rich members of the Beekmantown and Chazy Groups (Shuster, LaFleur, & Boylen, 1994), occur sporadically along the lake shore.

Hutchinson et al. (1981) were the first to study the sediment deposits beneath Lake George using seismic profiles and sediment cores. They found that the lacustrine sediments were underlain by undifferentiated glacial till deposits up to 50 meters thick (average 0–5 m). Glacio-lacustrine deposits composed of silty clay overlie the till and range from 0 to 20 m in thickness. In the southern basin, this layer is absent in waters shallower than 15 m, possibly the result of a low stand that eroded these sediments into the deeper basin at some undetermined time in the past. Organic Holocene lake deposits overlie these glacial deposits throughout the lake. The Holocene deposits are particularly thin in shallow water depths, again possibly due to erosion during one or more low stands.

A piece of wood found at 81–85 cm depth in a core sample of deepwater de-

posits was radiocarbon dated to 6950 before present (BP). This core was taken at the mouth of The Narrows in 47 m of water and had a total length of 6.9 m, the upper 2.5 m of which were organic Holocene deposits. On the basis of those studies, Hutchinson et al. (1981) hypothesized that a major low stand in lake level occurred sometime between 12,000 and 6950 years ago, and that most of the early Holocene sediment record at that site had been eroded and re-deposited into deeper parts of the lake basin. To our knowledge, there are no other published accounts of radiocarbon dating of long cores from Lake George.

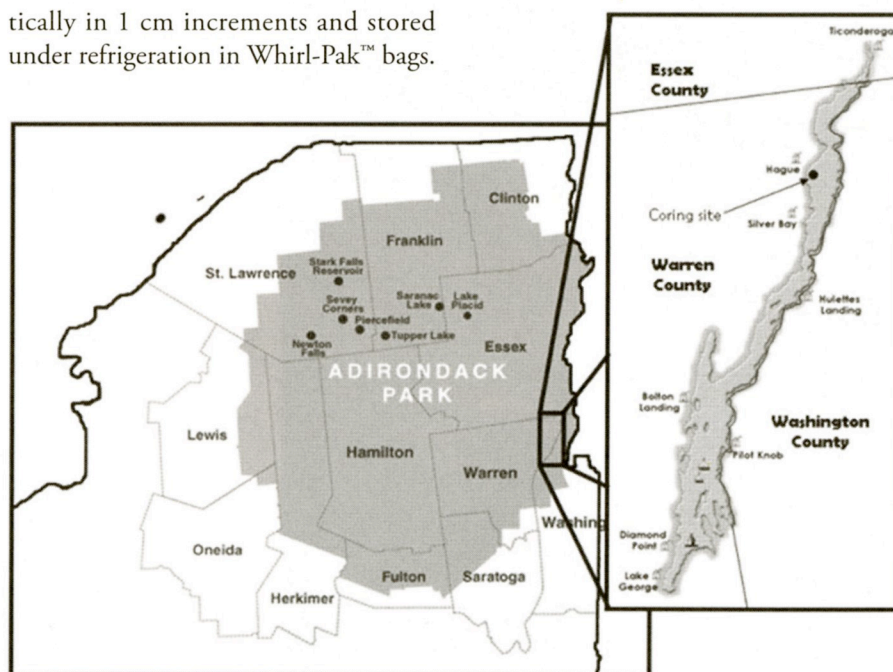
### Methods

In October, 2006, six sediment cores were retrieved from various depths in the northern end of Lake George (Figure 1). The core that we used for diatom analysis and radio-isotopic dating was collected from a water depth of 8 m on a submerged rise near the western shore using a micro-Kullenberg piston corer (LG-01; 43°44'39.78"N, 73°29'3.84"W). The other cores were taken in water depths ranging from 3 to 8 m.

The LG-01 core was extruded vertically in 1 cm increments and stored under refrigeration in Whirl-Pak™ bags.

The subsamples used for diatom analysis were cleaned of organic matter with hydrogen peroxide, and microscope slides were prepared with Permount™ mounting medium. Taxonomic identification was conducted at 1000X under oil immersion, and followed standard references (Patrick & Reimer, 1966). An average of 300 diatom valves were enumerated at each interval, but only 150 valves were enumerated at the 22–23 cm depth due to low abundance. The sediments were also analyzed for percent weight loss on ignition (%LOI) at 550°C in order to estimate organic content.

A piece of aquatic vegetation was removed from the 19 cm sample and sent to the University of Arizona for dating by accelerator mass spectrometry (AMS). The radiocarbon age was converted to calendar years using the CALIB 5.0.2 program (Stuiver, Reimer, & Reimer, 1981). In addition, <sup>210</sup>Pb dating of 12 samples of organic sediment was conducted by Flett Research, Ltd. (Ontario), using the Constant Rate of Supply model (Binford, Kahl, & Norton, 1993). A linear regression was used to infer the ages of older, 19th century sediments beyond the range of <sup>210</sup>Pb dating.



**Figure 1.** Study site, Lake George, New York (adapted from Bold Landing Area Map, 2007 and NYPA-Services, 2007)

## Results

The sediment stratigraphy of core LG-01 can be broken into three visually distinct sections. The upper 21 cm consisted of fine brown organic mud, the 21–23 cm section was a transitional zone, and the 23–30 cm section was a dense, grey silt/clay deposit (Figure 2). The same sediment profile was seen at five other coring locations in the north basin of the lake (Figure 3). Soil auger sampling by a SCUBA diver showed that the clay layer was more than 2 meters thick, and that it was the same kind of glacio-lacustrine deposit described by Hutchinson et al. (1981).

The  $^{210}\text{Pb}$  chronology showed signs of mixing in the upper 2.5 cm of the core (Figure 4), perhaps indicating bioturbation or hydrodynamic mixing. However,

because the core was taken in relatively deep water (8 m), it is more likely that the mixing was due to bioturbation. The  $^{210}\text{Pb}$  and  $^{226}\text{Ra}$  activities reached the same background levels in the bottom section of the core; this means that the deeper sediments are more than ca. 130 years old (Flett Research Ltd, 2007). Due to financial constraints, we did not obtain  $^{137}\text{Cs}$  data to corroborate the Pb-inferred age model. Therefore, if some of the top sediments were missing, our age calculations could be several years too young.

Two linear regressions were used to estimate a range of dates for the bottom of the organic layer, ranging from 165 to 200 years BP (Figure 4). The linear model that best fits the

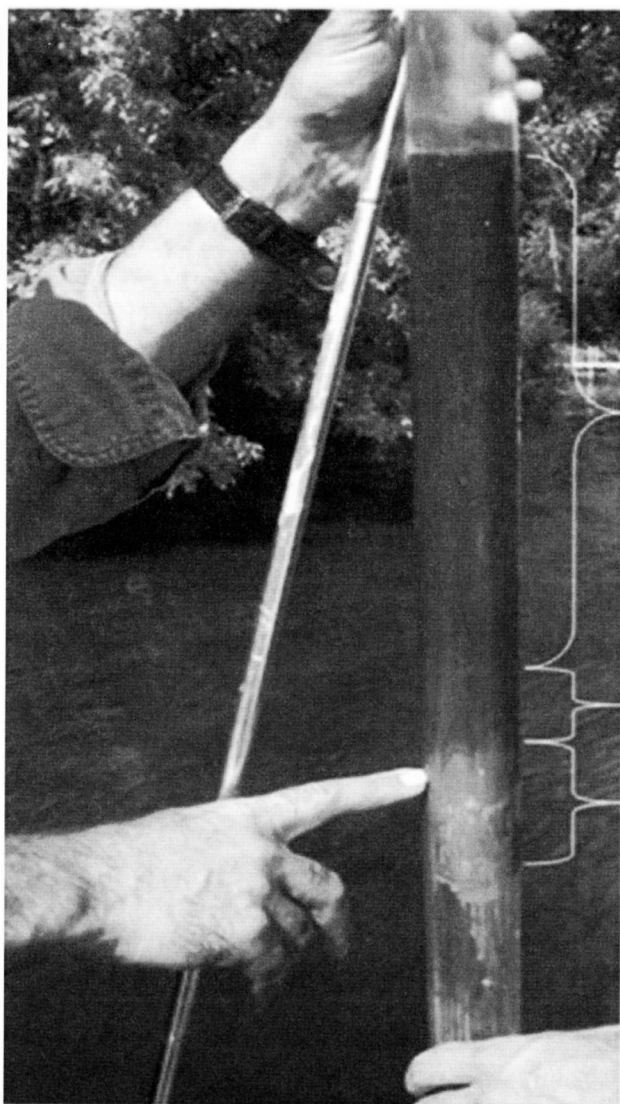


Figure 2. Sediment core (LG-01), Lake George, NY

Organic Layer

Transition Zone

Clay Layer

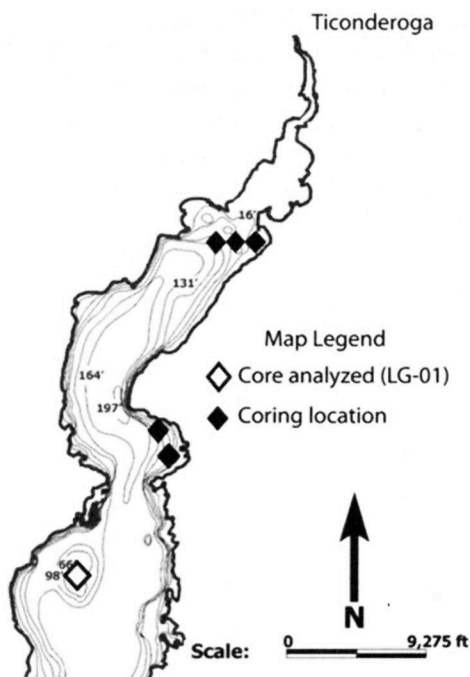


Figure 3. Coring locations in the north basin of Lake George

entire age-depth model yields an estimated age of 165 BP, but in this paper we will tentatively refer to the sedimentary transition as occurring roughly 200 years ago (ca. 1800 AD), though this is merely an estimate. Because the activity of  $^{210}\text{Pb}$  fell to background levels at 15.5 cm, precise dating was not possible below that depth in the core.

An aquatic plant taken from the 19.5 cm sediment sample yielded an AMS date of  $395 \pm 44$  BP (ca. 350 calendar years BP, or 1650 AD). However, our  $^{210}\text{Pb}$ -based age model infers a date of ca. 1800 AD for this depth. This apparent century-scale offset in dates suggests a possible contamination of the aquatic plant with old carbon, or a discontinuity in the profile below the dating range of  $^{210}\text{Pb}$ .

The %LOI data show a steady gradual rise in organic content from the top of the transition zone (21 cm) to the sediment surface (Figure 5). A rise in %LOI often indicates an increase in the production and/or preservation of organic matter in a lake, suggesting increased productivity, but it can also indicate a decrease in the deposition of inorganic sediments in the lake. The diatom evidence (discussed below) leads us to favor the first of these two possibilities.

The diatom community can be separated into three stratigraphic zones in the core, spanning the 23–20 cm (Zone 1), the 20–15 cm (Zone 2), and the 15–0 cm (Zone 3) intervals.



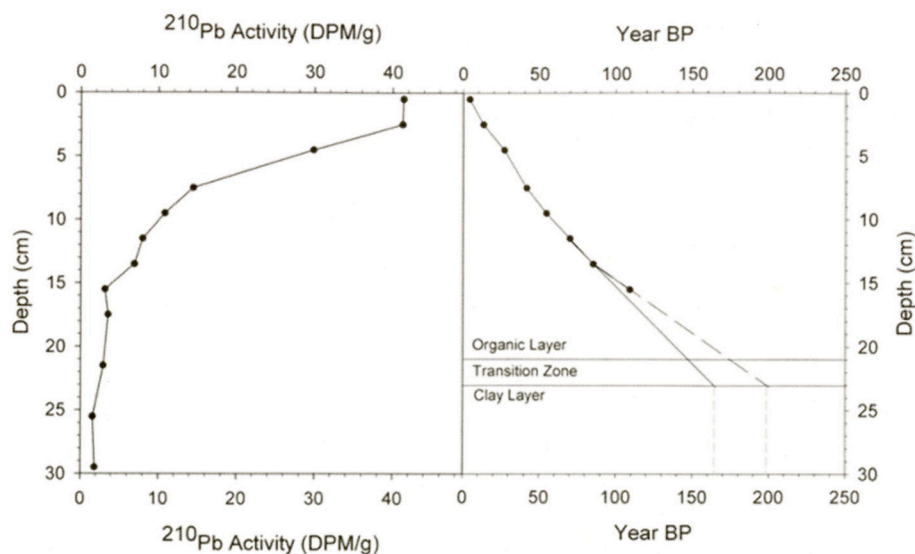


Figure 4. Lead-210 ( $^{210}\text{Pb}$ ) activity in the the sediment core analyzed (LG-01)

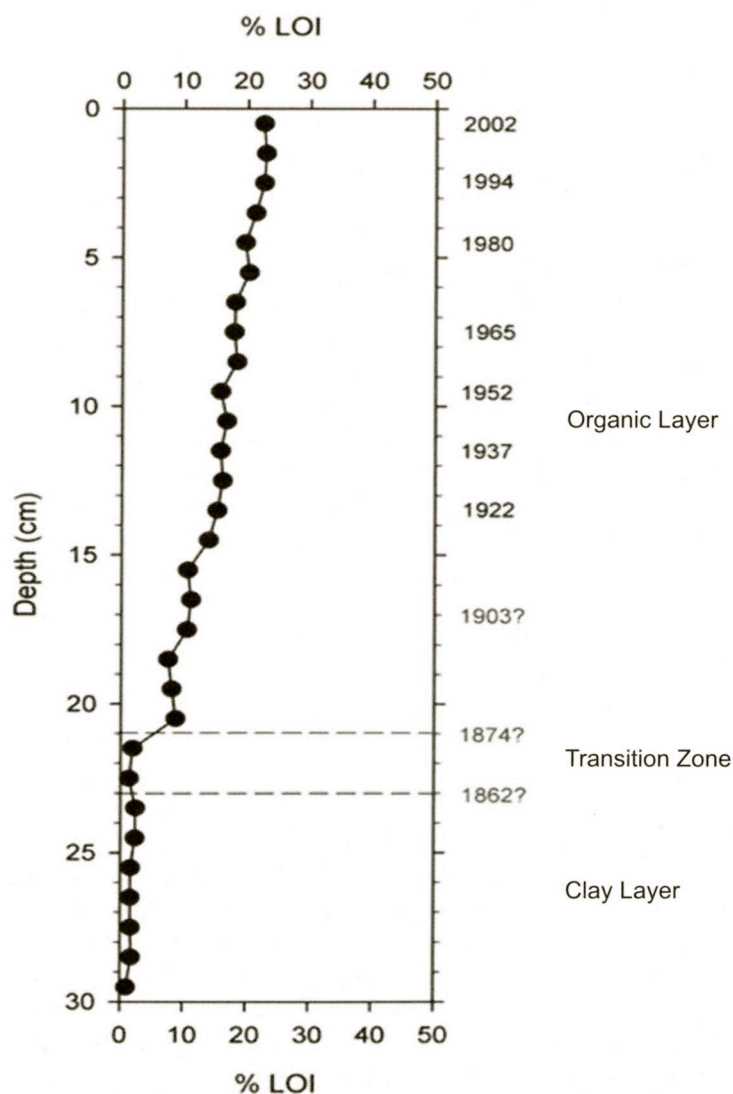


Figure 5. Percent weight loss on ignition (% LOI) for the Lake George sediment core (LG-01) through the first 30 cm of sediment

- In Zone 1, the diatom assemblages were dominated by *Achnanthes minutissima* and *Cocconeis placentula* (Figure 6). These are epiphytic taxa commonly found in association with aquatic macrophytes (Patrick & Reimer, 1966; Ács, Buczkó, & Lakatos, 1991), often in meso-to-eutrophic waters (Dixit et al., 1999). *Cyclotella bodanica* was also common in this zone; it is a planktonic diatom with wide ranges of ecological tolerances (Patrick & Reimer, 1966).
- In Zone 2, *A. minutissima*, *Cocconeis*, *C. bodanica*, decline while the percentages of benthic *Navicula*, *Fragilaria construens* and *F. pinnata* increased.

- In Zone 3, the epiphytic diatoms (*A. minutissima* and *Cocconeis*) and the planktonic diatoms (*C. bodanica* and small *Cyclotella*) increased again. The beginning of this zone was also marked by the appearance of planktonic *F. crotonensis* and a rise in the percentages of *Tabellaria flocculosa*. Both of these taxa are commonly associated with nutrient enrichment in the upstate New York region and elsewhere (Patrick & Reimer, 1966; Stager et al., 1997; Dixit et al., 1999).

## Discussion

The results of this study suggest that a trend of cultural eutrophication has begun in the northern waters of Lake George in recent times and that the lake experienced a severe drop in water levels, most likely in response to climatic conditions, some time during the last 200–350 years. We now discuss each of these conclusions in more detail, below.

### Eutrophication History

Because *F. crotonensis* and *T. flocculosa* are common indicators of increased productivity in North American lakes (Patrick and Reimer, 1996; Stager et al., 1997), their rising percentages above the 15 cm depth in the core (Figure 6) suggest that a trend of eutrophication has been under way in this part of the lake since the 1920's or so. Major development in the watershed as a whole began during the late 19th century (O'Brien, 1978), but it appears that the diatom community did not respond significantly to related changes in the lake until the early 20th century. Although the increased abundance of eutrophic diatoms might be expected to be accompanied by reduced water clarity and less light penetration to the benthos, the percentages of the epiphytic, bottom-dwelling species *A. minutissima* and *C. placentula* also increased, most likely because the



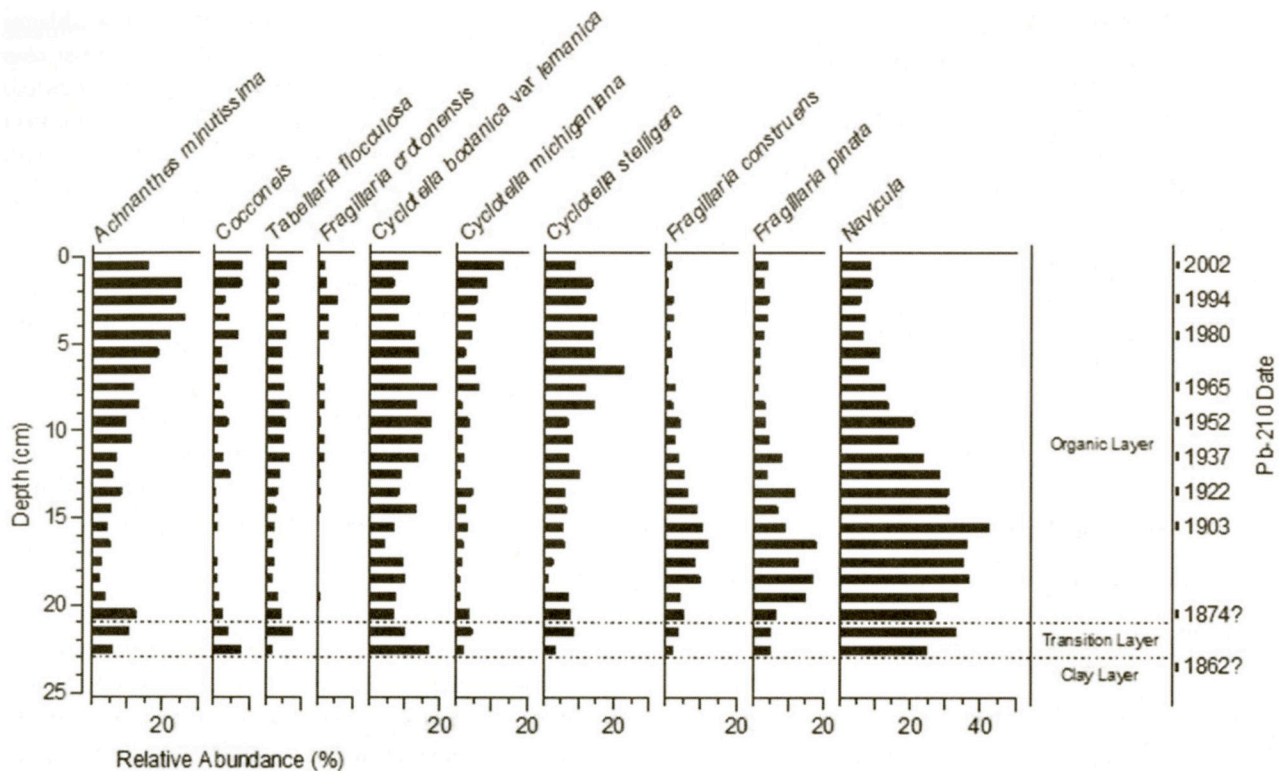


Figure 6. Relative abundance of the most common diatom taxa found in the Lake George sediment core (LG-01)

abundance of aquatic macrophytes upon which they grow also increased in response to nutrient enrichment (Boylen, Sheldon, & Whittaker, 1981).

The increasing % LOI values in the core (Figure 5) also suggest an increase in productivity in the northern end of the lake, and may indicate that the gradual eutrophication trend began even earlier than the diatom data suggest, perhaps as early as the beginning of the 19th century.

Our evidence for a eutrophication trend in the paleolimnological record of Lake George is consistent with historical reports of water quality declines (Bloomfield & Park, 1981), but to our knowledge the onset of that eutrophication trend has never been determined before. Recent efforts to address water quality problems in the lake (Pataki & Daneils, 2001) might have contributed to the recent decrease in the percentages of epiphytic diatoms (Figure 6), although we cannot be certain that this reflects a reduction in the abundance of macrophytes rather than continued decreases of water clarity.

#### Sediment History

The sedimentary profile in the core described here was also found in five other cores taken from the northern basin (Figure 3), and the similarity of these profiles from different sites shows that the silt/clay deposit is not simply an artifact due to a localized event such as dredging. Rather, we are reasonably certain that it represents the glaciolacustrine materials described elsewhere in the lake by Hutchinson et al. (1981). The organic, diatom-rich sediments overlaying that glacial clay layer represent only two centuries or so, which means that most of the last 10,000 years of post-glacial lacustrine sediment record is missing from these sites. Presumably, it has been mobilized and re-deposited in deeper portions of the lake basin at some time in the past.

A very similar sedimentary sequence has been reported in cores from neighboring Lake Champlain, as well (Levine et al., 2006). The appearance of this major stratigraphic hiatus in both lakes strongly suggests that it represents an environmental disturbance

that affected both basins simultaneously.

In theory, there are several mechanisms that could have produced such a sedimentary profile, most likely dredging, slumping due to a major earthquake, storm, or other mass wasting mechanism, or a significant drop in water level that exposed the loose organic sediments to wave-driven resuspension. Dredging is easily rejected as a cause in this case because of the wide geographic distribution of the hiatus. Large-scale slumping usually requires steep slopes, but many of our sampling sites were flat or only gently sloping, and such a disturbance would not be limited to all of the shallowest portions of Lake George as this feature appears to be.

We believe that the hiatus in our cores represents a lake surface low stand of several meters that must have occurred sometime during the last 200–350 years. This hitherto unidentified, relatively recent low stand might have been similar to the one that Hutchinson et al. (1981) invoked to explain large-scale sediment erosion in the basin sometime between



12,000 and 6,950 years ago during the warm, relatively dry early Holocene.

The diatom community structure at the bottom of the core supports the idea of a low-stand in the water level (Figure 6). The high abundance of *Cocconeis* at the bottom of the organic layer in Zone 1, along with the absence of *F. crotonensis*, probably represents higher light penetration to the lake bottom due to a thinner water column, as does the high abundance of other benthic taxa.

The water level of Lake George is now controlled by a dam on the northern outlet to Lake Champlain. The current version of the dam has been in place since 1903, but the original dam was built in 1798 (Chilson et al., 2003). The natural outlet of the lake lies ca. 2 meters below the top of the current dam (Shuster et al., 1994), which suggests that dam construction alone can account for no more than 2 meters of lake level rise above a preceding natural low stand. Our coring site lay in 8 meters of water, so a 2 meter drop in water level would still leave 6 meters of water covering the coring site, which is probably still deep enough to protect the sediments from most wave-driven erosion. It is therefore likely that the water level dropped significantly as a result of a shift in regional climatic conditions.

We do not know at this time if the density of the silt/clay layer was simply due to inherent physical features of the fine-grained sediments, or if it was also the result of subaerial exposure during the low stand. If the latter is the case, then the water level lay at least 8 meters below the level of today's lake.

Several paleoclimatic records from the northeastern United States and southeastern Canada registered droughts during the late 19th century (Cook and Jacoby, 1971; Buckley et al., 2004). A very severe drought also developed in the Lower Hudson Valley, south of Lake George, during the so-called "Medieval Warm Period" of 800–1350 AD (Pederson et al., 2005). A long sustained period of drought such as this could have removed most of the Holocene sedi-

ments, and a later, perhaps less severe drought 350–150 years ago would have only needed to erode a few centuries' worth of sediment in order to produce the hiatus observed in Lake George.

A drought in 1880 caused the water level in the Champlain Canal to drop low enough to impair shipping, though none of the droughts after 1880 seem to have had a similar effect (Chilson et al., 2003). Reports also indicate that New York City was close to running out of water during the summers of 1876, 1877, and 1880 (Boylan et al., 1981). A dry period such as this may also have been severe enough to lower the water level of Lake George, but it occurred too late to account for the hiatus in our cores.

A Palmer Drought Severity Index record for the Lower Hudson Valley spanning the last 300 years (Cook & Jacoby, 1979) contains evidence of several relatively moderate but prolonged droughts in the region since 1770 AD. Due to the limitations of our age model, however, we cannot conclusively link the Lake George low stand to any particular drought in the Hudson Valley record, and it is even possible that it pre-dated that record.

We find no clear evidence in the historical records that we have examined for eyewitness accounts of such a low stand. This might argue for an earlier (ca. 1650–1750 AD) date for the event, but it is also possible that the lake was still recovering from the low stand when the first Euro-Americans settled the watershed, and that fluctuating and/or rising lake levels therefore seemed too "normal" to report at the time. Such conditions might even have provided the initial incentive for construction of the original dam on the outlet in 1798.

## Conclusions

The diatom communities in the northern portion of Lake George appear to have changed significantly in response to cultural eutrophication since the early 20th century. In addition, our study shows that the Lake George watershed

has experienced one or more droughts during the last 350–150 years that were apparently severe enough to drop the level of the lake by several meters. Although our study does not provide a precise date for that event, it demonstrates that, in historically recent times, the lake has been sensitive enough to climatic conditions to respond with extreme changes in surface level. This finding highlights the importance of monitoring and predicting hydrological conditions in the Lake George watershed as human-driven climate change complicates the natural range of rainfall and drought variability in the region.

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*Whitewater rafting on the Adirondacks' Hudson River*

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